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# EARLY DETECTION OF DAMAGE IN HEAVY DUTY COMBUSTION TURBINE BLADES FOR ELECTRIC GENERATION

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PRESENTED BY: G. TIRONE
PISA 27/9/2000

* **ENEL PRODUZIONE S.p.A. TORINO - ITALY**

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# BACKGROUND

- THE HEAVY DUTY GAS TURBINES ARE THE FUNDAMENTAL COMPONENTS FOR THE MODERN COMBINED CYCLE POWER PLANTS

- ENEL PRODUZIONE ALREADY OPERATES COMBINED CYCLE TECHNOLOGY IN ITS POWER PLANTS (TRINO AND LA SPEZIA) IN ADDITION TO OTHER KINDS OF STEAM-GAS CYCLE (FEEDWATER HEATING AND IP STEAM INJECTION) IN MONTALTO, ROSSANO, AND TERMINI POWER PLANTS

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# BACKGROUND

- **IN THESE POWER PLANTS THE HEAVY DUTY GAS TURBINES HAVE BEEN OPERATED UP TODAY MAINLY AT BASE LOAD TRYING TO KEEP MAINTENANCE ACTIVITIES AS SHORT AS POSSIBLE IN ORDER TO OBTAIN HIGH AVAILABILITY OF THE PLANT**

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# BACKGROUND

- IT IS VERY IMPORTANT TO FORESEE THE MAINTENANCE ACTIVITIES FOR THE WHOLE PLANT LIFE, INCLUDING REFURBISHMENTS AND REPLACEMENTS OF GAS TURBINE HOT COMPONENTS, IN ORDER TO RESPECT LIFE CYCLE COST OF THE PLANT

- ACCORDING TO THE SUGGESTIONS OF THE OEM'S, ALL THE UTILITIES SCHEDULE THE MAINTENANCE ACTIVITIES FOR GAS TURBINES ON A "TIME BASED PRACTICE"

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# BACKGROUND

- THE MOST FOLLOWED MAINTENANCE SCHEDULE FORESEES COMBUSTION INSPECTIONS EVERY 8000 EOH, HOT GAS PATH INSPECTIONS EVERY 24000 EOH AND MAJOR OVERHAULS EVERY 48000
- THE MAINTENANCE ACTIVITY SCHEDULE CAN BE MODIFIED BASED ON BORESCOPIC INSPECTIONS AND TURBINE OPERATING PARAMETERS ("CONDITION BASED MAINTENANCE")

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# PURPOSE OF THE PRESENTATION

- **TO DESCRIBE 2 FAILURES OCCURRED ON BLADES OF ENEL HEAVY DUTY GAS TURBINES AND THE DETECTING TECHNOLOGIES TUNED UP IN ORDER TO HAVE A REALISTIC ASSESSMENT OF BLADES CONDITION TO SET UP THE BEST MAINTENANCE INTERVENTION**

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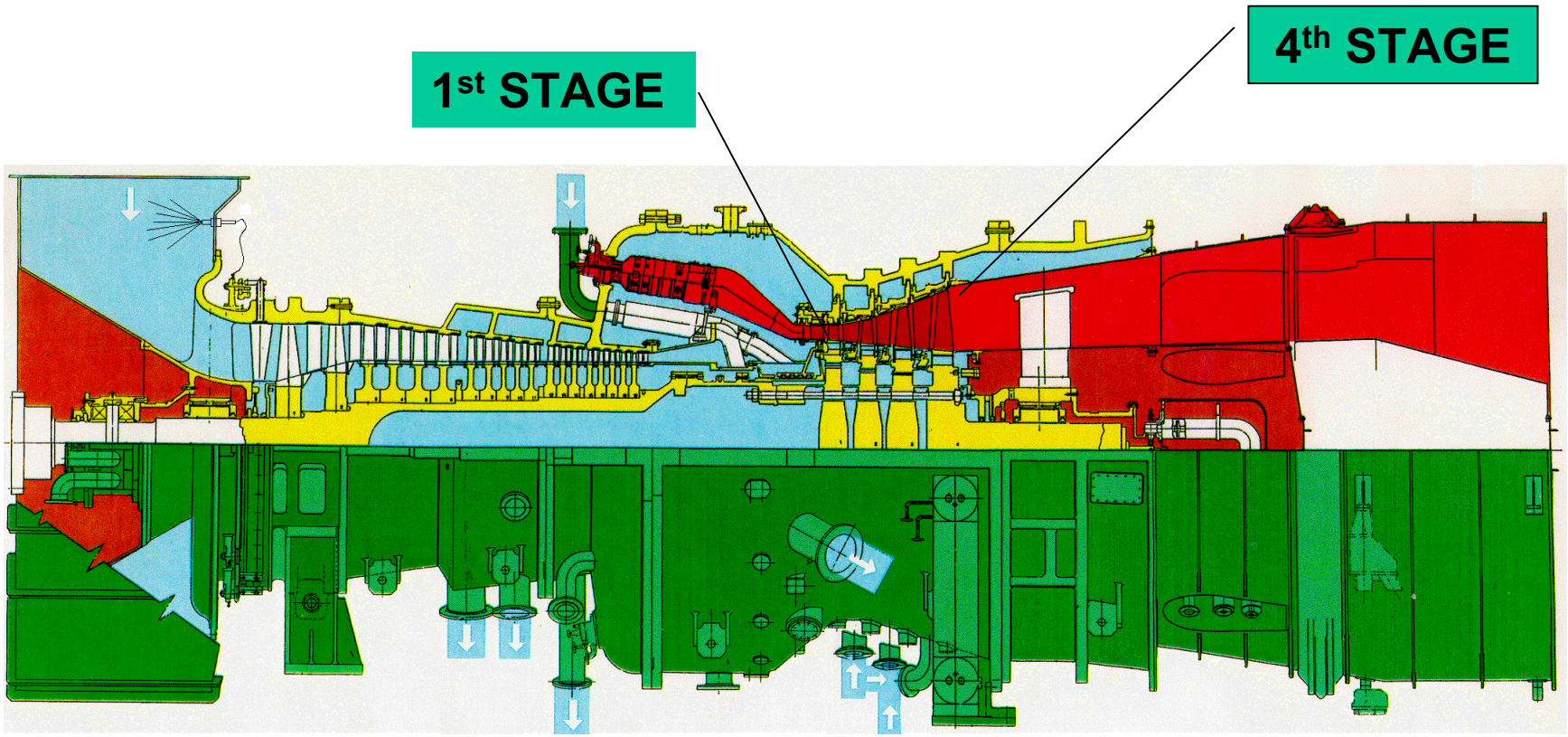
# SKETCH OF FAILED GAS TURBINES



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# MAIN TECHNICAL DATA OF THE GAS TURBINE INVOLVED IN THE FAILURES

- POWER OUTPUT (ISO): 125 MW
- COMPRESSOR STAGE NO.: 19
- COMPRESSION RATIO: 14:1
- TURBINE INLET TEMPERATURE (TIT): 1162°C
- EXHAUST GAS TEMPERATURE: 495°C
- EXHAUST GAS FLOW RATE: 453 KG/SEC
- TYPE OF COMBUSTION SYSTEM: DLN K-POINT

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# ENEL FLEET OF GTs SIMILAR TO FAILED ONES

| UNIT | OUTPUT (MW) | 1ST SYNCR. | OPERATING HOURS | STARTS | COMBUSTION SYSTEM | LOAD REJECTIONS |
|---|---|---|---|---|---|---|
| TO12 | 125 | 07/12/95 | 16659 | 139 | DLN | 2 |
| TO13 | 125 | 10/10/96 | 17584 | 137 | DLN | 2 |
| TO22 | 125 | 29/08/97 | 8250 | 94 | DLN | 2 |
| TO23 | 125 | 09/10/97 | 10360 | 85 | DLN | 2 |
| MC12 | 125 | 14/07/92 | 8665 | 514 | DLN | 10 |
| MC13 | 130 | 08/09/92 | 8170 | 464 | WI | 10 |
| MC22 | 130 | 09/04/92 | 9044 | 461 | WI | 10 |
| MC23 | 130 | 16/04/92 | 9452 | 508 | WI | 10 |
| LR1 | 130 | 16/12/92 | 2669 | 382 | DRY | 0 |
| LR2 | 130 | 01/12/92 | 2837 | 443 | DRY | 0 |
| TI42 | 125 | 29/02/96 | 6731 | 108 | DLN | 3 |
| TI52 | 125 | 02/12/95 | 6579 | 134 | DLN | 3 |

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# MAIN FAILURES EXPERIENCED

- 4TH ROTATING STAGE BLADE FAILURE
- 1ST ROTATING STAGE BLADE CRACKS IN THE PLATFORM

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# 4TH STAGE BLADE FAILURE DESCRIPTION

- THE FAILURE HAPPENED ON THE UNIT TRINO 12
- AFTER A LOAD REJECTION TEST THE GAS TURBINE TRIPPED DUE TO LOW SPEED/HIGH VIBRATIONS
- THE GAS TURBINE EXPERIENCED, AT THE MOMENT OF THE FAILURE, 16659 OPERATING HOURS AND 139 STARTS
- DURING THE FOLLOWING INSPECTION THROUGH THE MANHOLE ON THE TURBINE DISCHARGE DUCT THE LOSS OF 1-4TH STAGE BLADE WAS FOUND
- DAMAGES ON OTHER 4TH STAGE BLADES, 4TH STAGE VANES AND DISCHARGE DIFFUSER WERE FOUND TOO

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# MAIN OPERATING DATA OF THE GAS TURBINE INVOLVED IN THE FAILURE

- 1ST SYNCHRONIZATION YEAR: 1995
- OPERATING HOURS FROM 1ST SYNCR.: 16.659
- STARTS FROM 1ST SYNCR.: 139
- YEAR OF LAST HGPI: 1998
- OPERATING HOURS FROM LAST HGPI: 4513
- STARTS FROM LAST HGPI: 26

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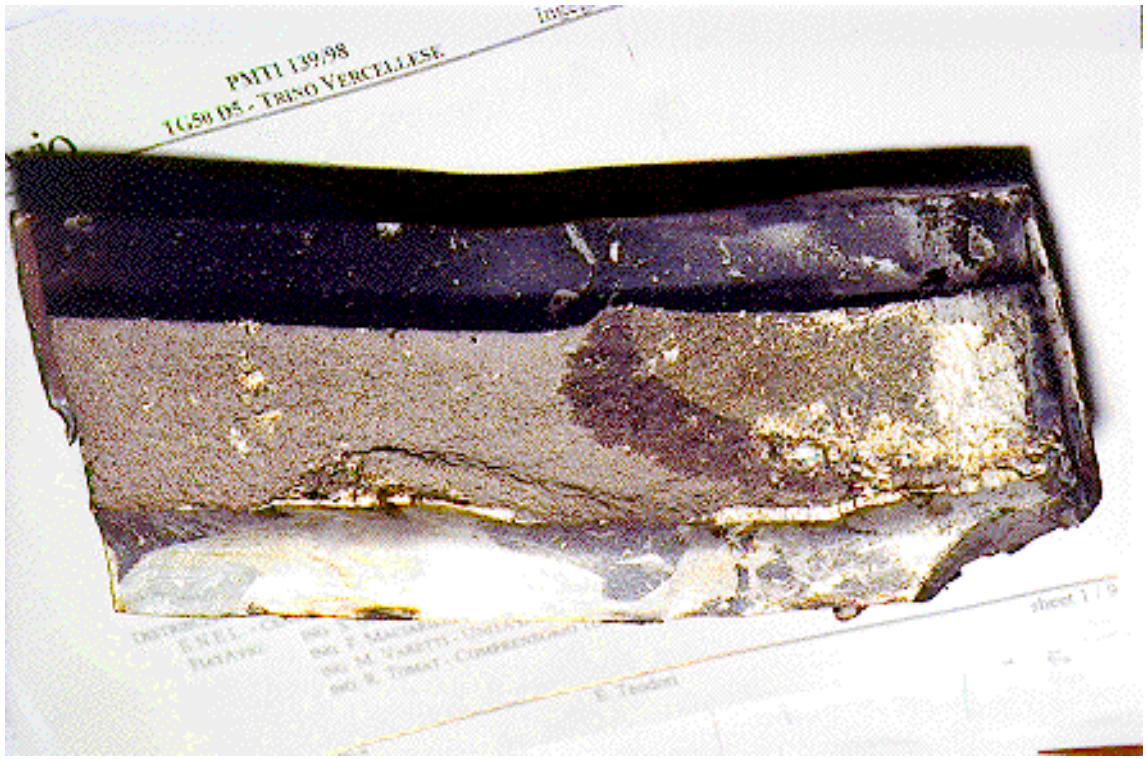
# BLOCK OF 4TH STAGE FAILED BLADE



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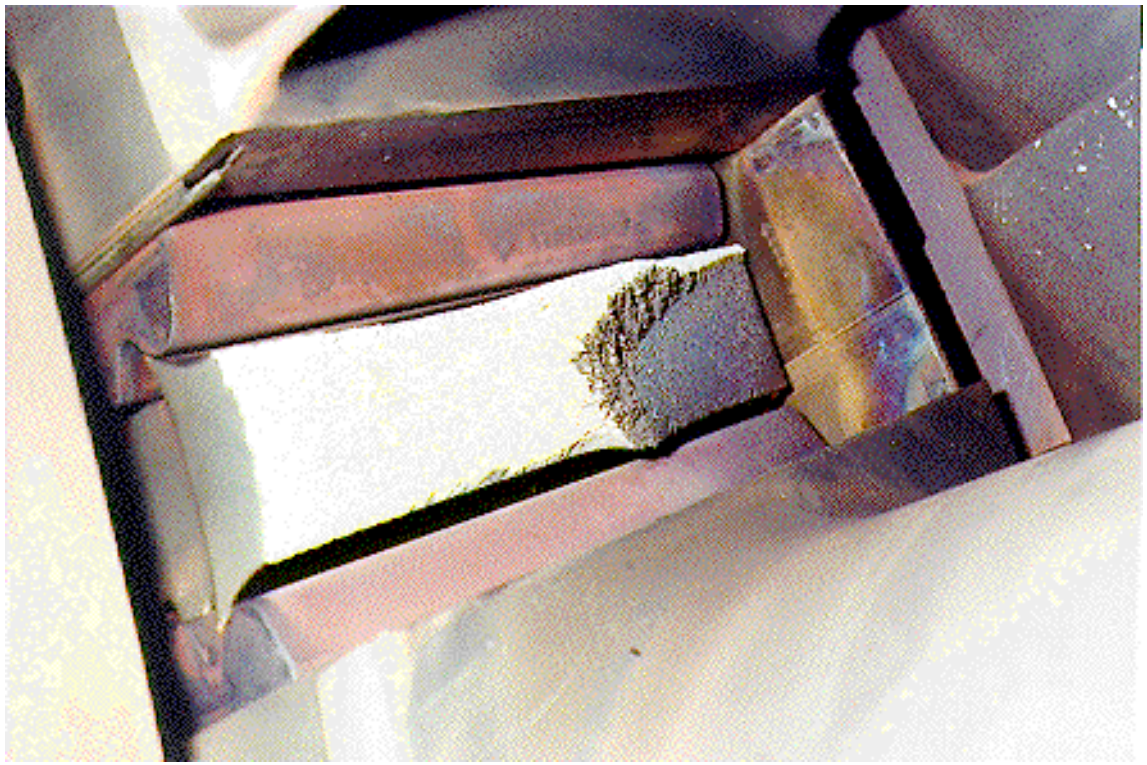
# RESIDUAL BLOCK OF FAILED BLADE



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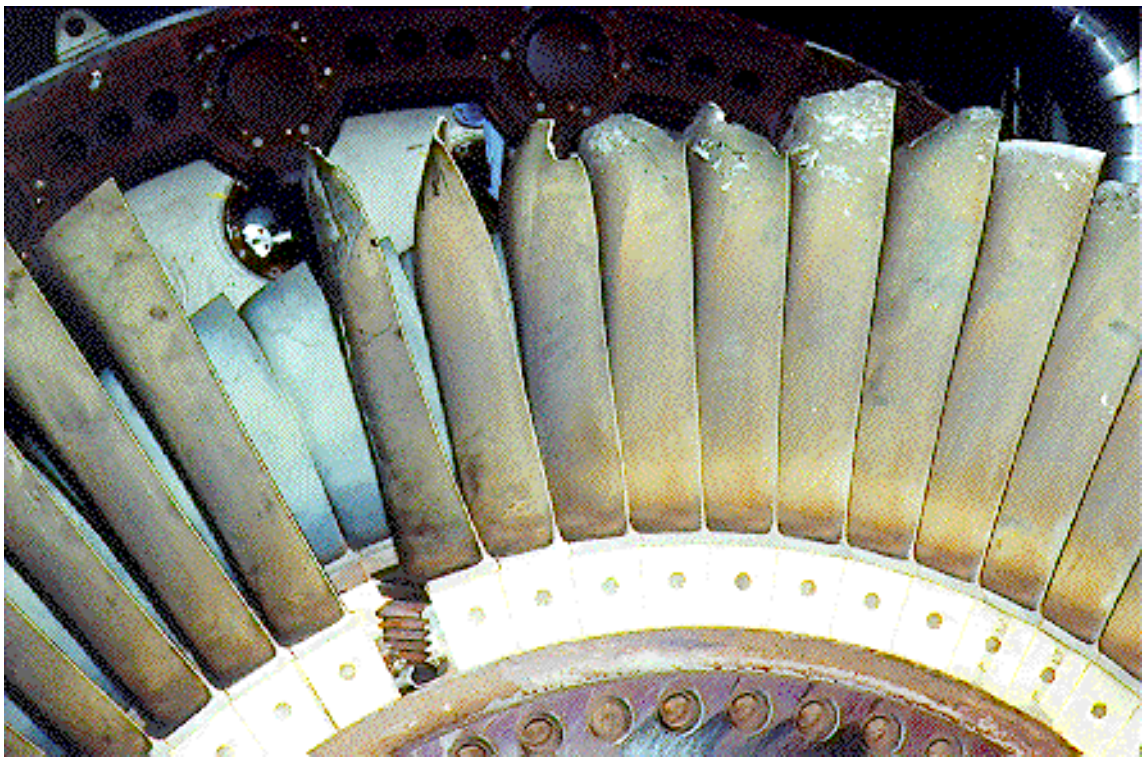
# 4TH STAGE BLADES AFTER THE FAILURE



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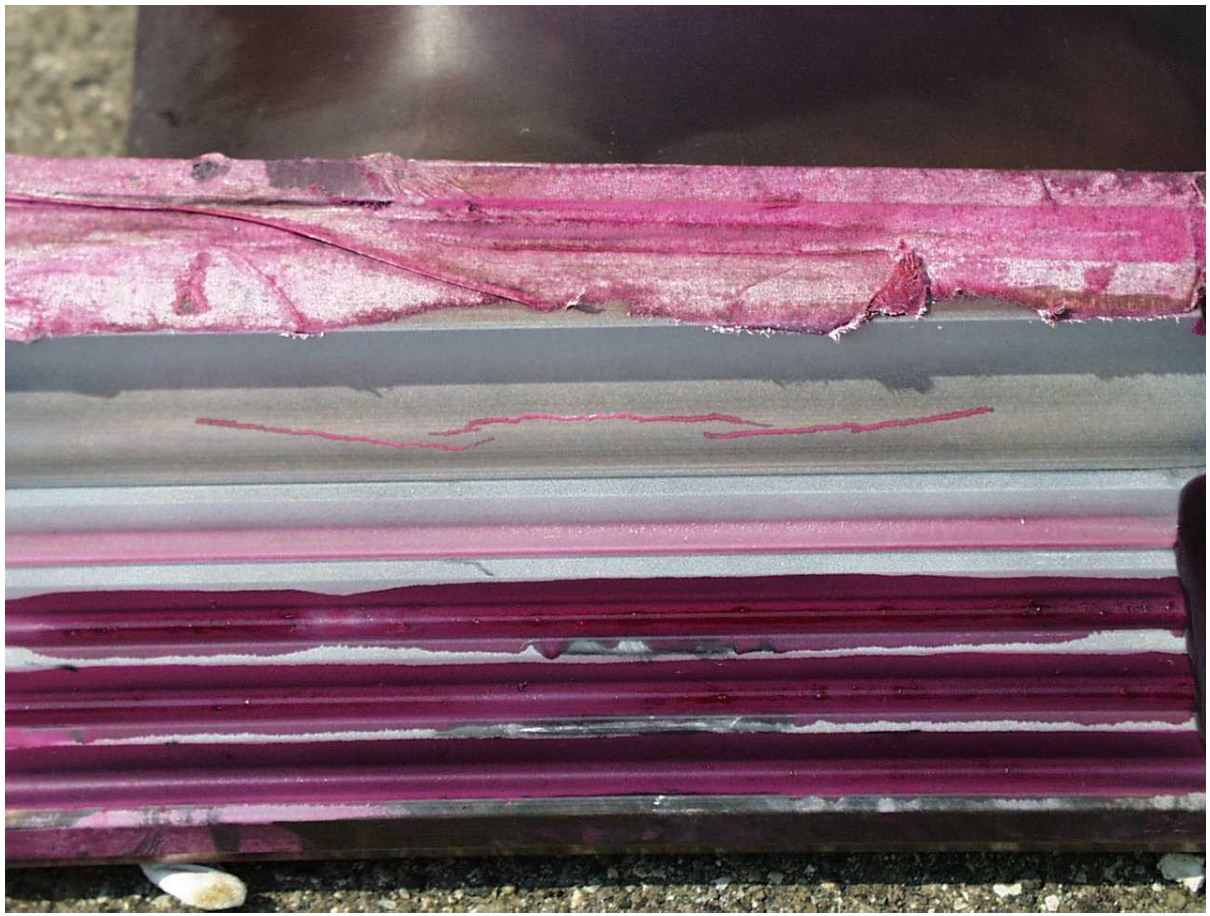
# TYPICAL CRACKS DETECTED ON SHANK AREA OF 4TH STAGE BUCKETS



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# INVESTIGATIONS AGREED WITH THE MANUFACTURER

- INVESTIGATIONS ON OTHER SIMILAR GAS TURBINES OF ENEL FLEET
- CHEMICAL AND METALLOGRAPHIC ANALYSIS OF FAILED BLADE
- VERIFICATION OF DESIGN CALCULATIONS OF 4TH STAGE BLADE
- PRESSURE PULSATION TESTS ON DLN COMBUSTION SYSTEMS

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# INVESTIGATIONS ON THE ENEL GTs SIMILAR TO FAILED ONE

- ENEL DEVELOPPED UT TESTS IN ORDER TO INSPECT THE 4TH STAGE BLADE ROOTS OF SIMILAR UNITS INSTALLED IN ENEL FLEET WITHOUT TURBINE CASING REMOVAL
- IN ADDITION TO FAILED ONE, ANOTHER SIMILAR GAS TURBINE, EQUIPPED WITH DLN COMBUSTORS TOO, WAS FOUND AFFECTED BY 4TH STAGE BLADE CRACKS ON 2 BLADES.
- ALL THE OTHER 5 SIMILAR DLN AND 3 W/I GTs OF ENEL FLEET DID NOT SHOW THE PRESENCE OF 4TH STAGE BLADE CRACKS

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# RESULTS OF PRELIMINARY INVESTINGATIONS

- 4TH STAGE BLADE BASE MATERIAL WAS COMPLYING WITH MANUFACTURERS SPECIFICATION AND NO ORIGIN DEFECTS WERE FOUND
- THE 4TH STAGE BLADE WAS “AS DESIGNED”
- THE CAUSE OF THE FAILURE SHOULD HAVE BEEN CYCLICAL STRESSES OF RELEVANT INTENSITY AND OF BENDING TYPE, WHICH LET THE 4$^{TH}$ STAGE BLADE VIBRATE AT THE NATURAL FREQUENCY OF 172 Hz
- ONLY DLN GTs WERE FOUND AFFECTED BY THE FAILURE

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# PRESSURE PULSATION TESTS IN DLN COMBUSTION SYSTEM

- AFTERWARD THE INVESTIGATION WAS AIMED TO RESEARCH PECULIAR SERVICE CONDITIONS CHARACTERIZED BY THE PRESENCE OF ALTERNATING HIGH STRENGHT STRESSES
- DLN COMBUSTION SYSTEMS, IF NOT WELL SET, ARE ABLE TO PRODUCE LOW FREQUENCY (LOWER THAN 60 Hz) PRESSURE PULSATIONS WHICH MIGHT EXCITE NATURAL VIBRATION FREQUENCY OF DOWNSTREAM TURBINE BLADES

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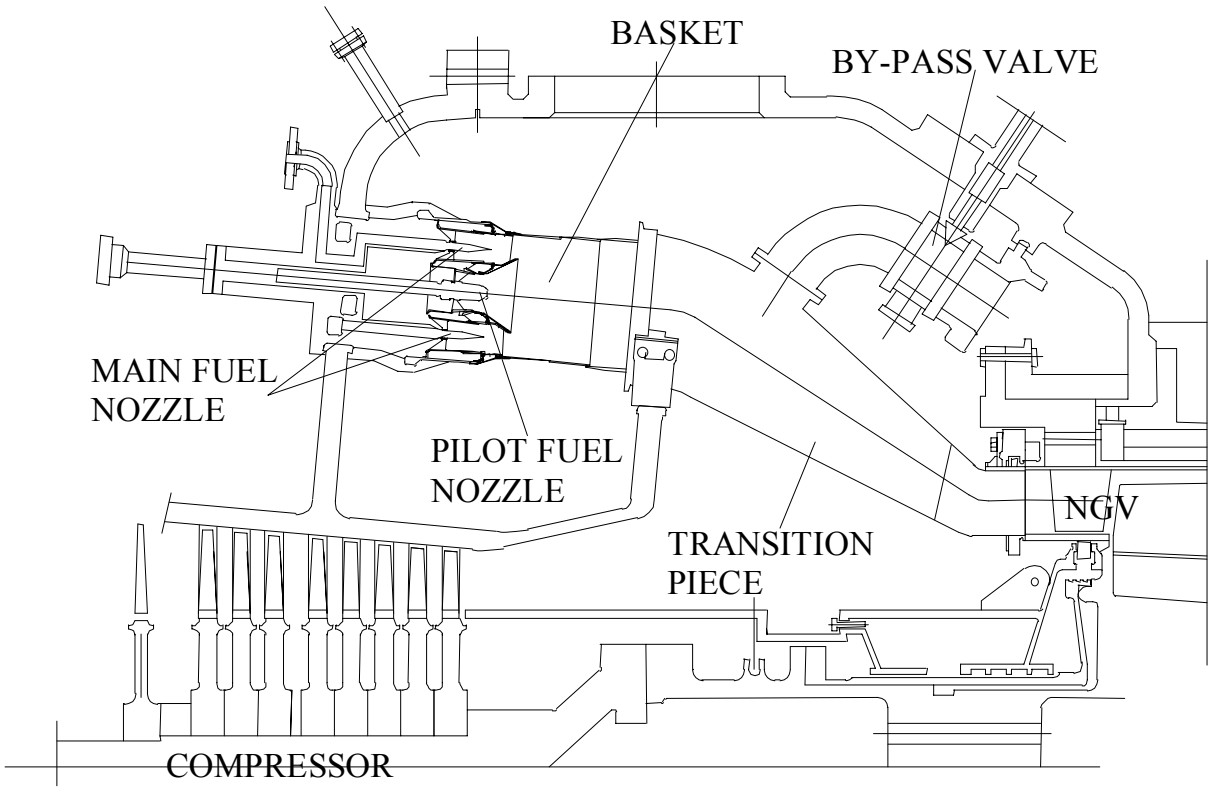
# TYPICAL DLN COMBUSTION SYSTEM



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# RESULTS OF PRESSURE PULSATION TESTS IN DLN COMBUSTION SYSTEM

- THE DLN MAIN PARAMETERS OF ENEL GTs LIKE SIMILAR TO FAILED ONE ARE “ON DESIGN”
- DURING THE SERVICE WITH “ON DESIGN” DLN PARAMETERS PRESSURE PULSATION VALUES DANGEROUS FOR 4TH STAGE BLADE WERE NOT DETECTED
- BY THE REDUCTION OF P/T PARAMETER WITH RESPECT TO DESIGN VALUE AN INCREASE OF THE 23 Hz-PRESSURE PULSATION LEVEL WAS NOTICED
- (23Hz IS A FREQUENCY ABLE TO EXCITE THE NATURAL VIBRATION FREQUENCY (173 Hz) OF 4TH STAGE BLADE OF GTs SIMILAR TO FAILED ONE: 173=23+3*50)

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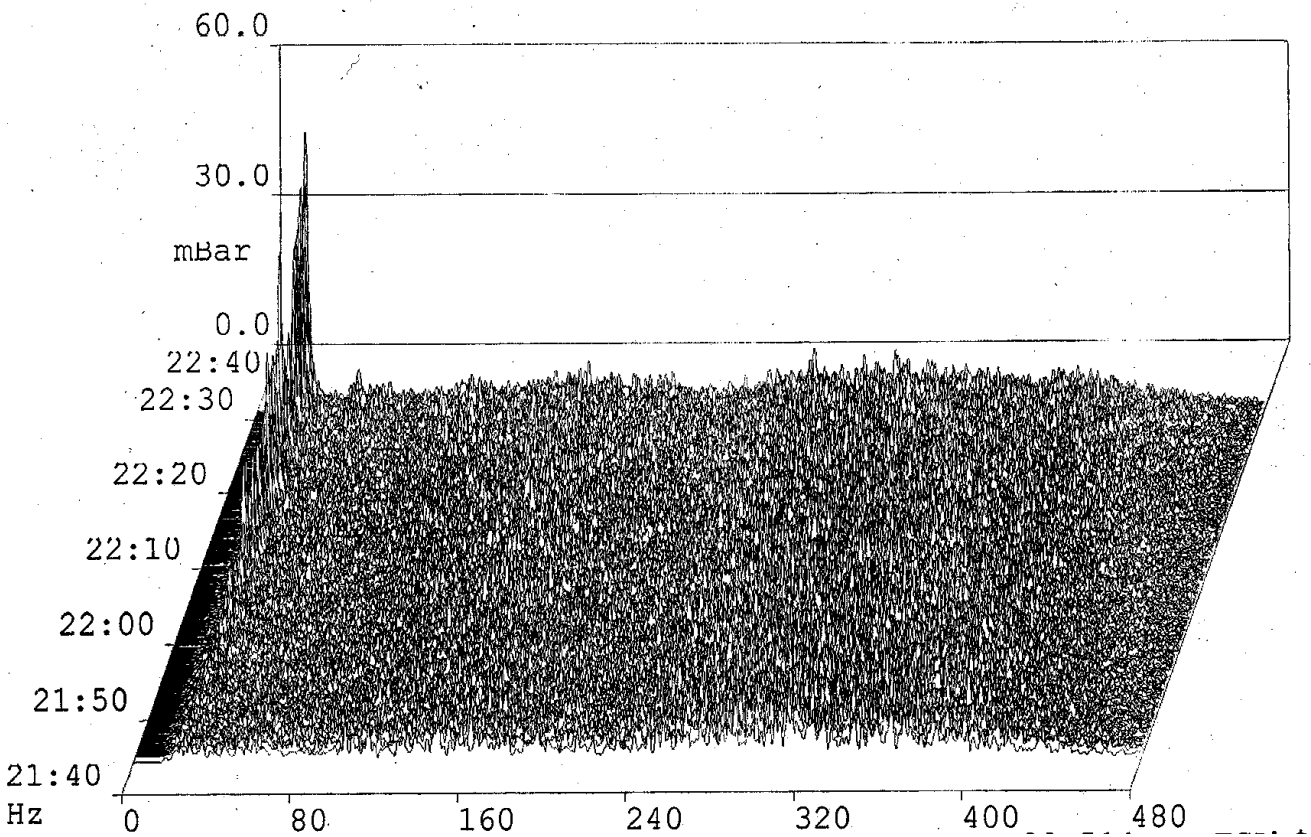
# 23 Hz- PRESSURE PULSATIONS PRODUCED BY DLN DURING P/T CONTROLLED MODIFICATIONS



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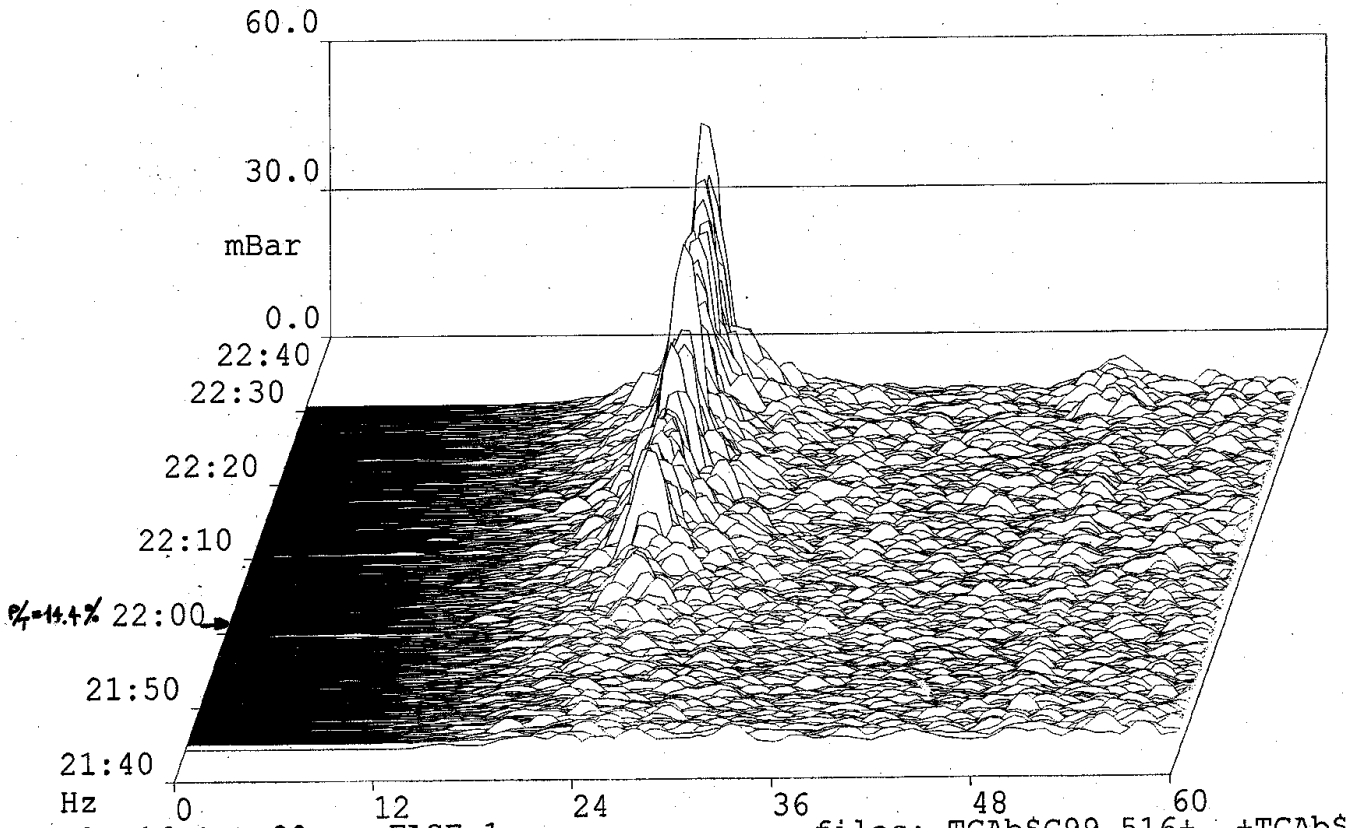

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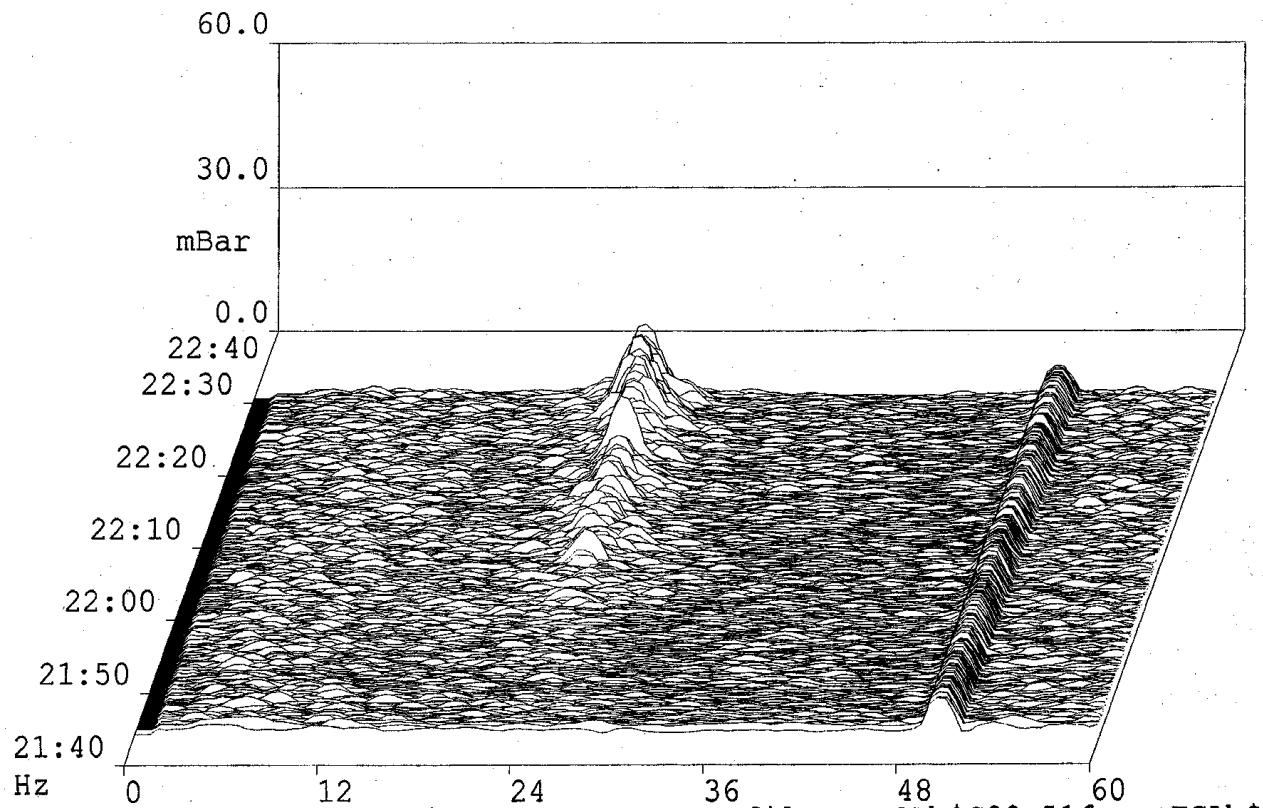
# 23 HZ-TURBINE EXHAUST-GAS DYNAMIC PRESSURE PRODUCED DURING P/T MODIFICATIONS



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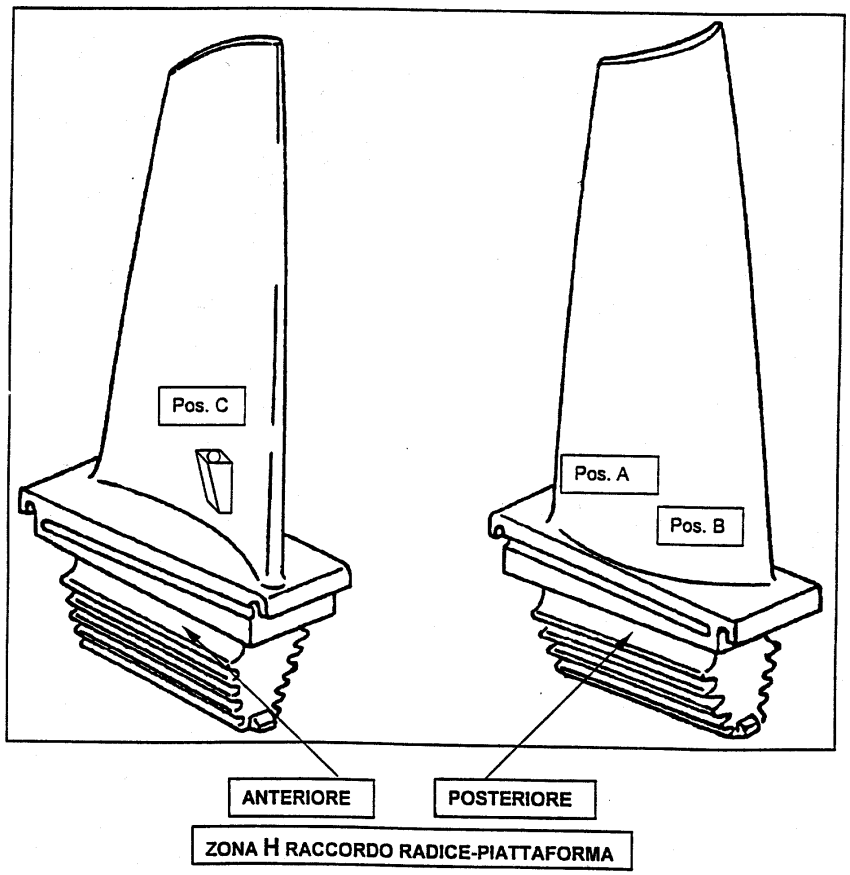
# 4TH STAGE BLADE FAILURE CONCLUSIONS

- 2-125 MW GAS TURBINES OF ENEL FLEET EXPERIENCED CRACKS ON 4TH STAGE BLADE ROOTS (IN ONE CASE THE IN SERVICE-FAILURE OF A BLADE OCCURRED)
- DLN PRESSURE PULSATIONS ARE THE CAUSE OF THE FAILURE
- IN ORDER TO AVOID SIMILAR FAILURES ENEL FORESEES THE FOLLOWING DETECTING TECHNOLOGIES:
  - 4TH STAGE BLADE INSPECTIONS BY UT TECHNIQUE EVERY 8000 EOH (ONLY FOR DLN UNITS)
  - THE ON-LINE MONITORING OF PRESSURE PULSATIONS IN THE COMBUSTION CHAMBERS

# UT TECNIQUE APPLIED FOR THE EARLY DETECTION OF 4TH STAGE BLADE CRACKS



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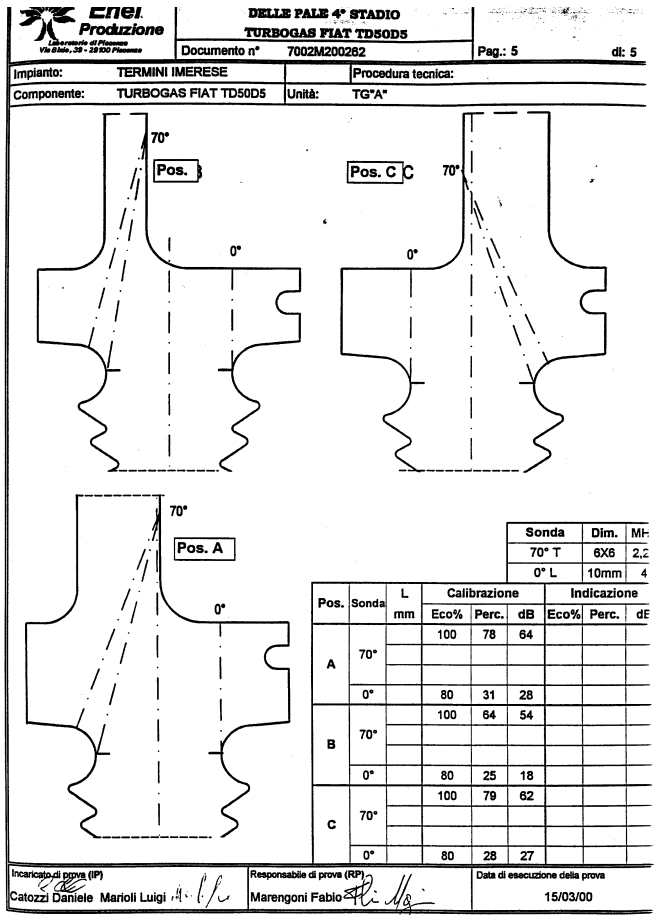
# UT TECNIQUE APPLIED TO 4TH STAGE BLADE FAILURE



Enel Produzione — Laboratorio di Piacenza, Via G.Ibdo, 29 - 29100 Piacenza

DELLE PALE 4° STADIO
TURBOGAS FIAT TD50D5

Documento n° 7002M200282 — Pag.: 5 di: 5

Impianto: TERMINI IMERESE — Procedura tecnica:

Componente: TURBOGAS FIAT TD50D5 — Unità: TG"A"



| Sonda | Dim. | MH |
|---|---|---|
| 70° T | 6X6 | 2,2 |
| 0° L | 10mm | 4 |

| Pos. | Sonda | L mm | Calibrazione Eco% | Perc. | dB | Indicazione Eco% | Perc. | dB |
|---|---|---|---|---|---|---|---|---|
| A | 70° | | 100 | 78 | 64 | | | |
| | 0° | | 80 | 31 | 28 | | | |
| B | 70° | | 100 | 64 | 54 | | | |
| | 0° | | 80 | 25 | 18 | | | |
| C | 70° | | 100 | 79 | 62 | | | |
| | 0° | | 80 | 28 | 27 | | | |

Incaricato di prova (IP): Catozzi Daniele Marioli Luigi

Responsabile di prova (RP): Marengoni Fabio

Data di esecuzione della prova: 15/03/00

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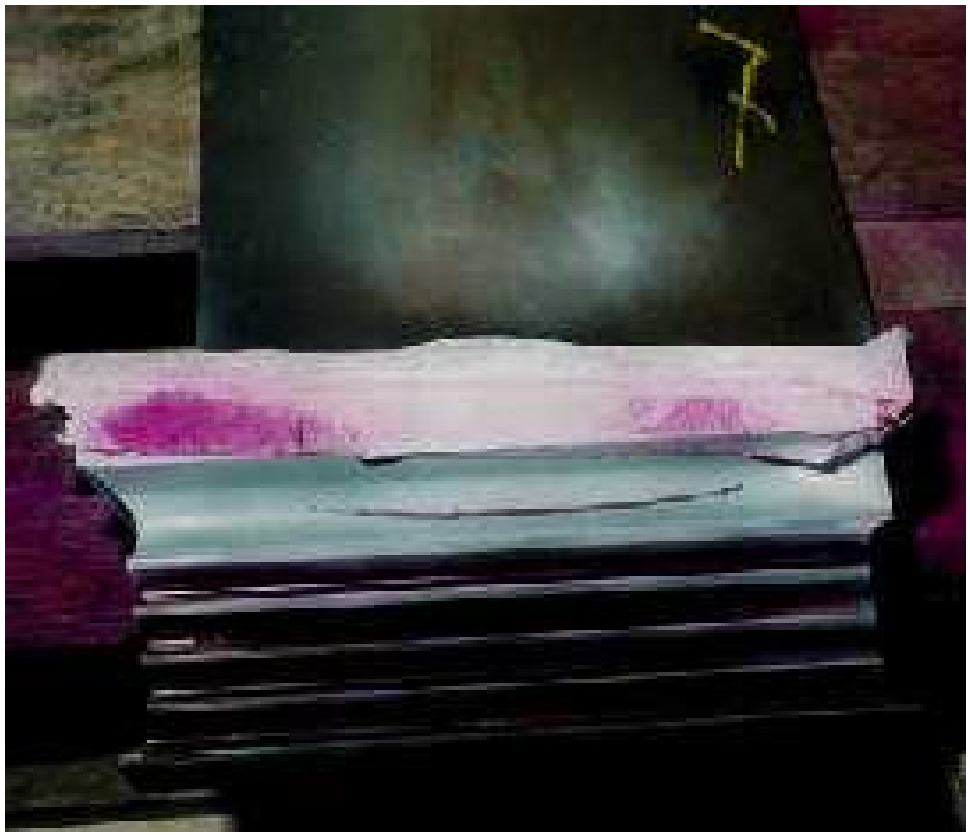

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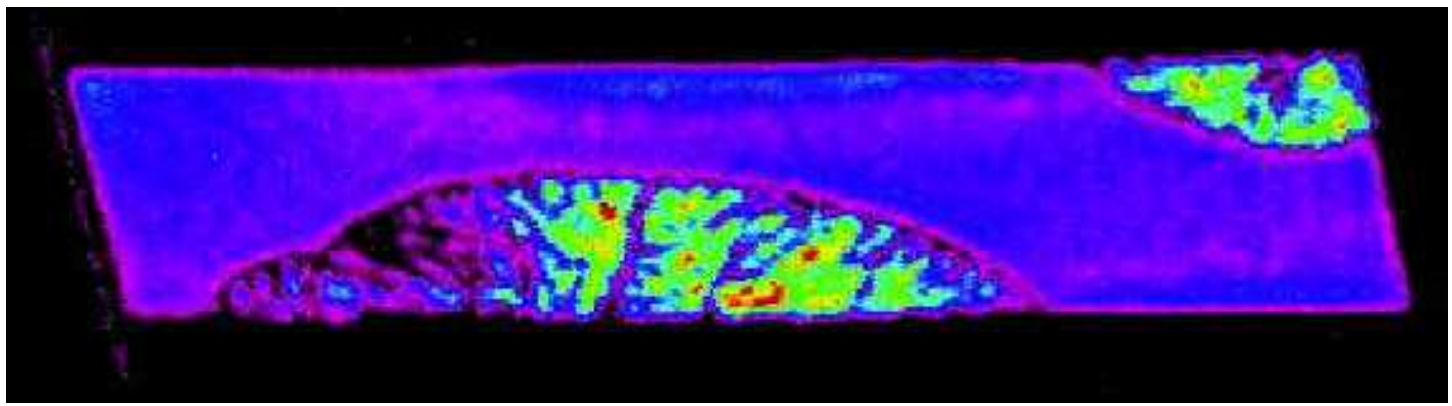

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# UT TECNIQUE APPLIED TO 4TH STAGE BLADE FAILURE

- THE UT TECNIQUE TUNED UP IN ORDER TO PREVENT THE 4TH STAGE BLADE FAILURE CAN BE APPLIED WITHOUT THE TURBINE CASING REMOVAL ENTERING INTO THE TURBINE DISCHARGE DUCT THROUGH THE MANHOLE
- BECAUSE OF THE HCF CRACKS CAN BE INCUBATED AT THE BEGINNING AND NOT DETECTABLE BY UT TEST IF THE CRACK DEPTH IS LOWER THAN 3 mm , ENEL FORESEES TO CARRY OUT UT TESTS ON 4TH STAGE BLADE ROOTS EVERY 8000 EOHs DURING THE OUTAGE FOR COMBUSTION INSPECTION

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# CRACKS ON 1ST STAGE BLADE PLATFORM

- THE PROBLEM WAS DETECTED ON 3 GTs ;
- CRACKS ARE RADIAL, AND WERE DETECTED AFTER COATING STRIPPING ONLY, AND NOT BEFORE BY NORMAL FLUORESCENT DYE PENETRANT TEST;
- THE TYPE OF OPERATION AND THE SUPPLIERS OF THESE 3 ROWS ARE DIFFERENT;

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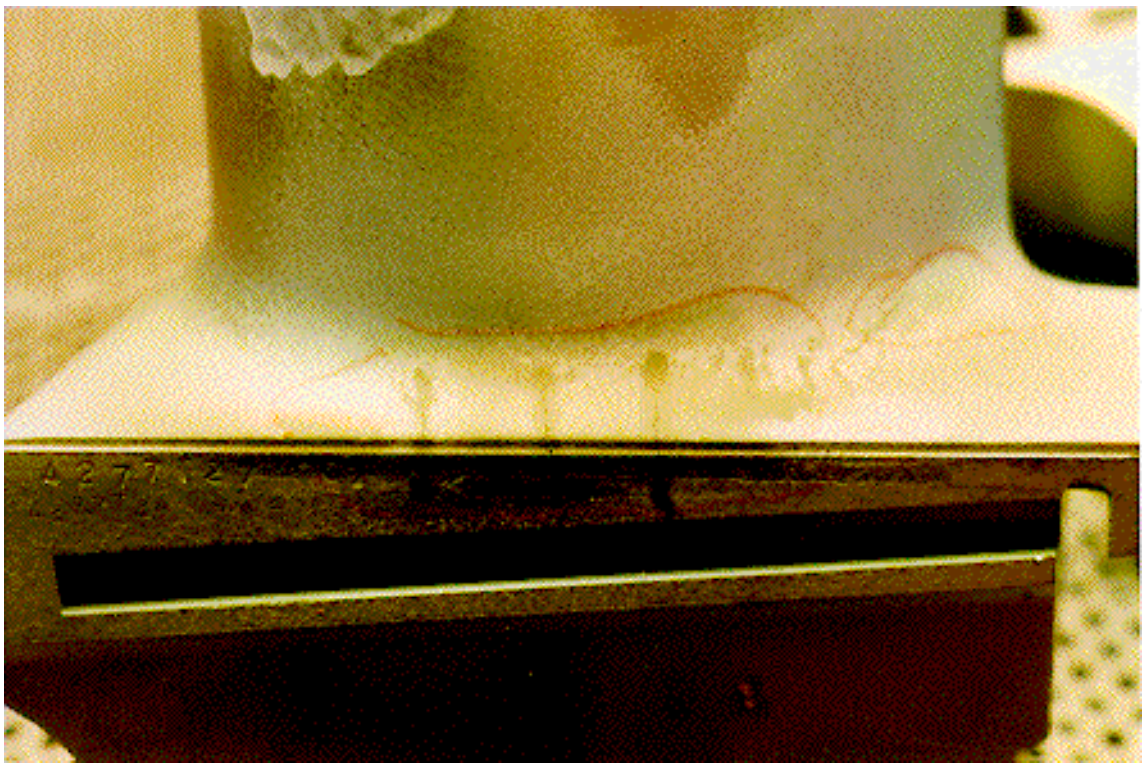
# CRACKS ON THE PLATFORM OF THE 1ST STAGE BLADES



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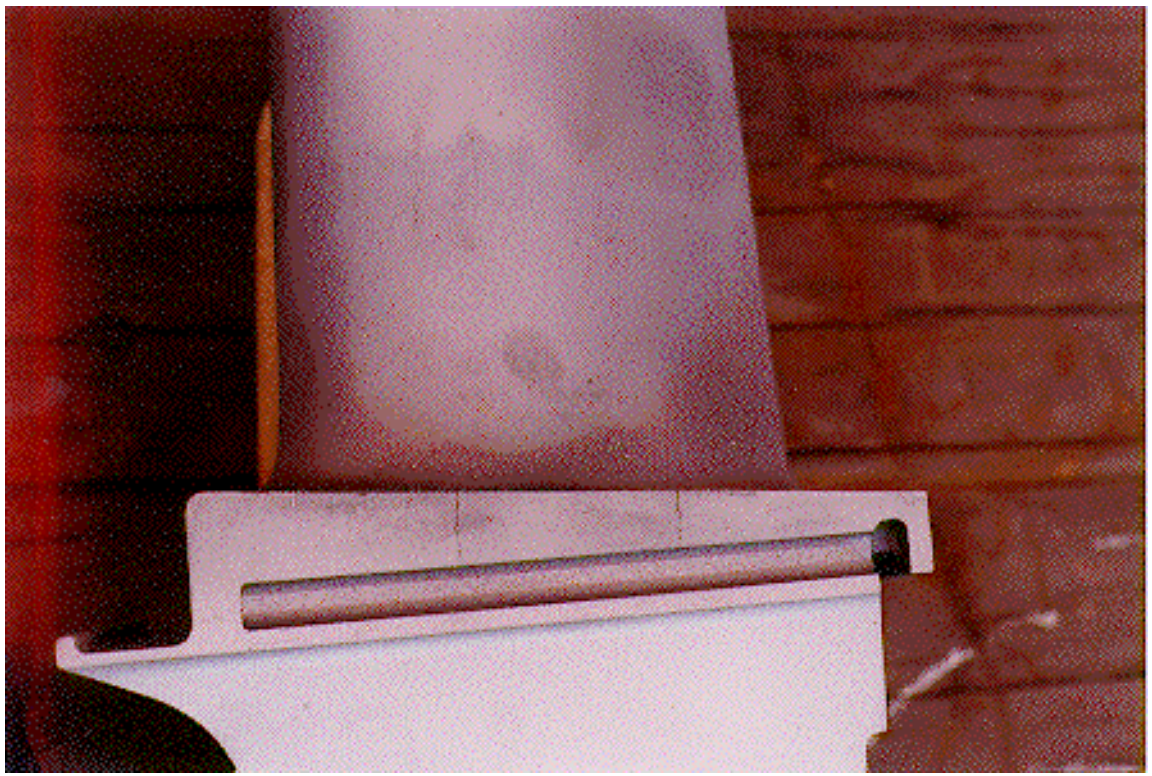
# CRACKS ON THE PLATFORM OF THE 1ST STAGE BLADES



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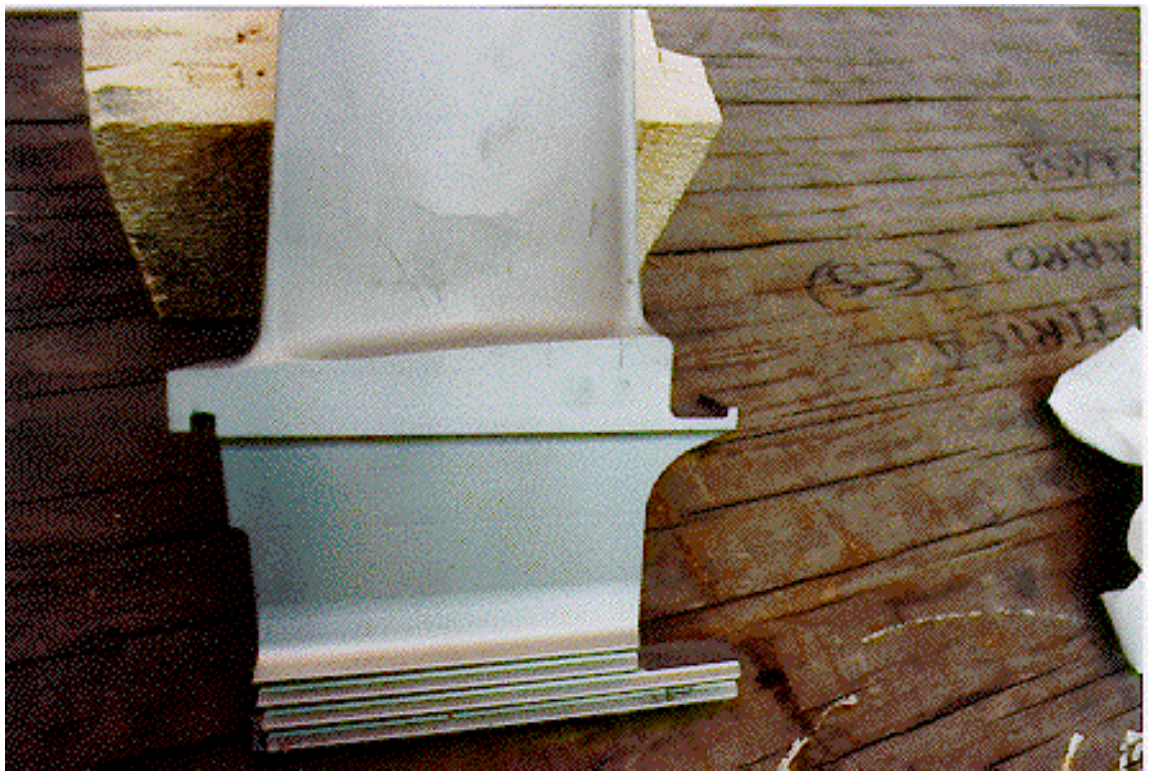
# CRACKS ON THE PLATFORM OF THE 1ST STAGE BLADES



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# METALLOGRAPHICAL ANALYSIS

- A GREAT CONTRIBUTE TO THE CRACK PROPAGATION WAS REPRESENTED BY THEMOMECHANICAL FATIGUE
- THE GAMMA PRIME PHASE ANALYSIS SUGGESTS THAT IN 2 CASES OF THE 3 ONES EXPERIENCED THE BLADES WERE EXPOSED TO EXCESSIVE TEMPERATURE
- IN THE THIRD EXPERIENCED CASE, UNCORRECT BLADE COOLING IS SUSPECTED
- ANOTHER CONTRIBUTE TO THE CRACK PROPAGATION WAS PROBABLY REPRESENTED BY THE ABSENCE OF RELIEVING TREATMENT OF MATERIAL PRIOR TO BLADE COATING STRIPPING

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# DETECTING TECHNOLOGIES

- IN ORDER TO DETECT THE CRACKS UNDER THE COATING, ENEL TUNED UP AN EDDY CURRENT TEST
- IN ORDER TO ANALYZE THE 1ST STAGE BLADE PLATFORMS, ENEL UTILIZES THIS TEST WITHOUT BLADE REMOVAL EVERY 8000 HOURS DURING THE COMBUSTION INSPECTIONS (ONLY FOR FIAT GTs, IS POSSIBLE TO REMOVE 1ST STAGE VANES WHITHOUT REMOVING THE CASING)

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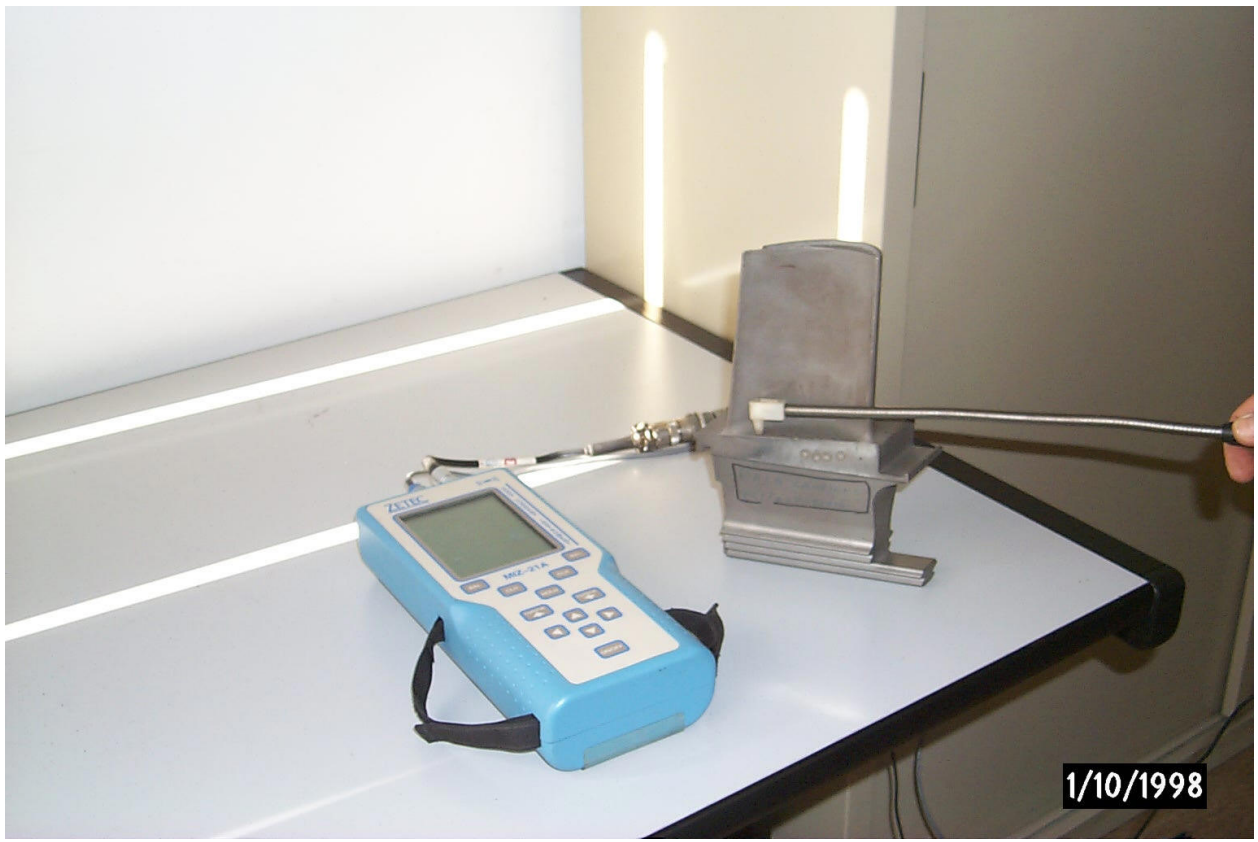
# EDDY CURRENT TEST APPLIED TO 1ST STAGE BLADE CRACKS



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# EDDY CURRENT TEST APPLIED TO 1ST STAGE BLADE CRACKS

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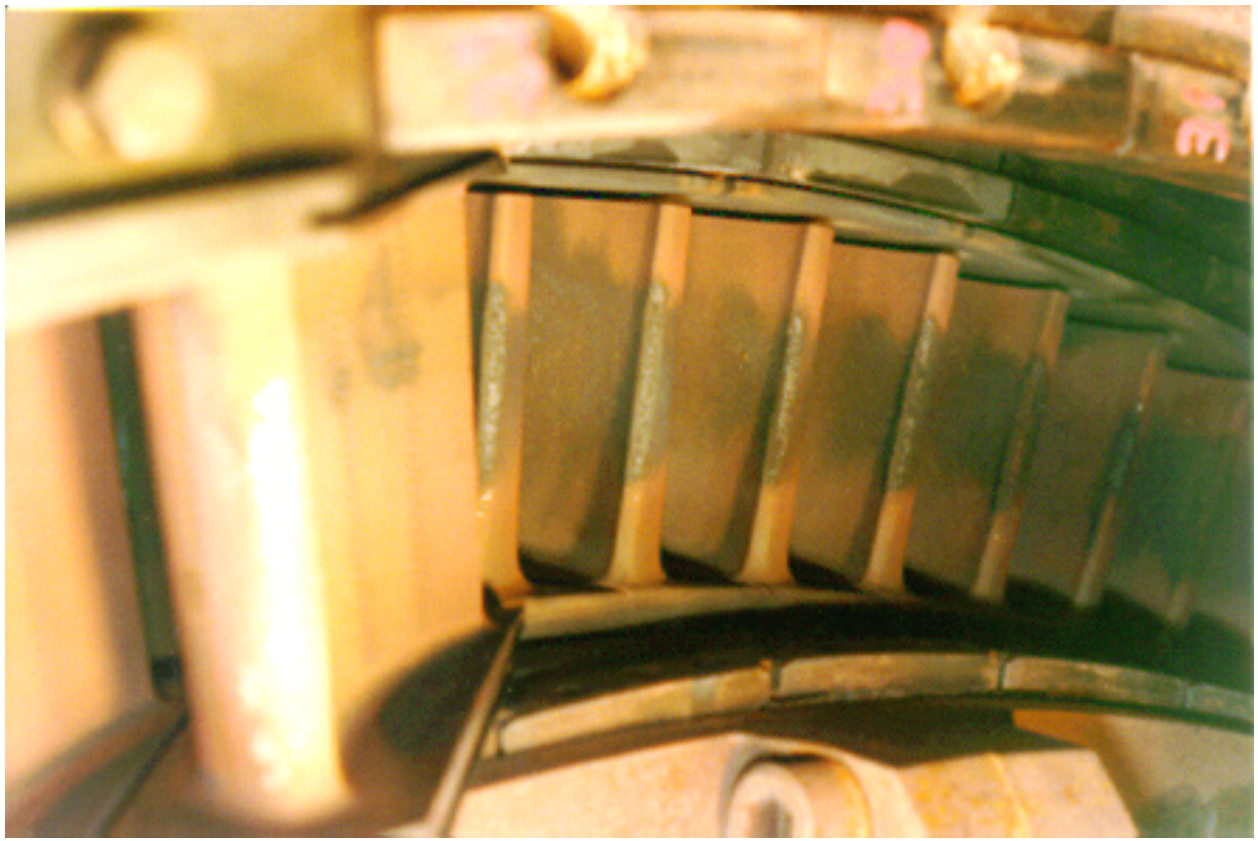
# FIRST STAGE ROTATING BLADES



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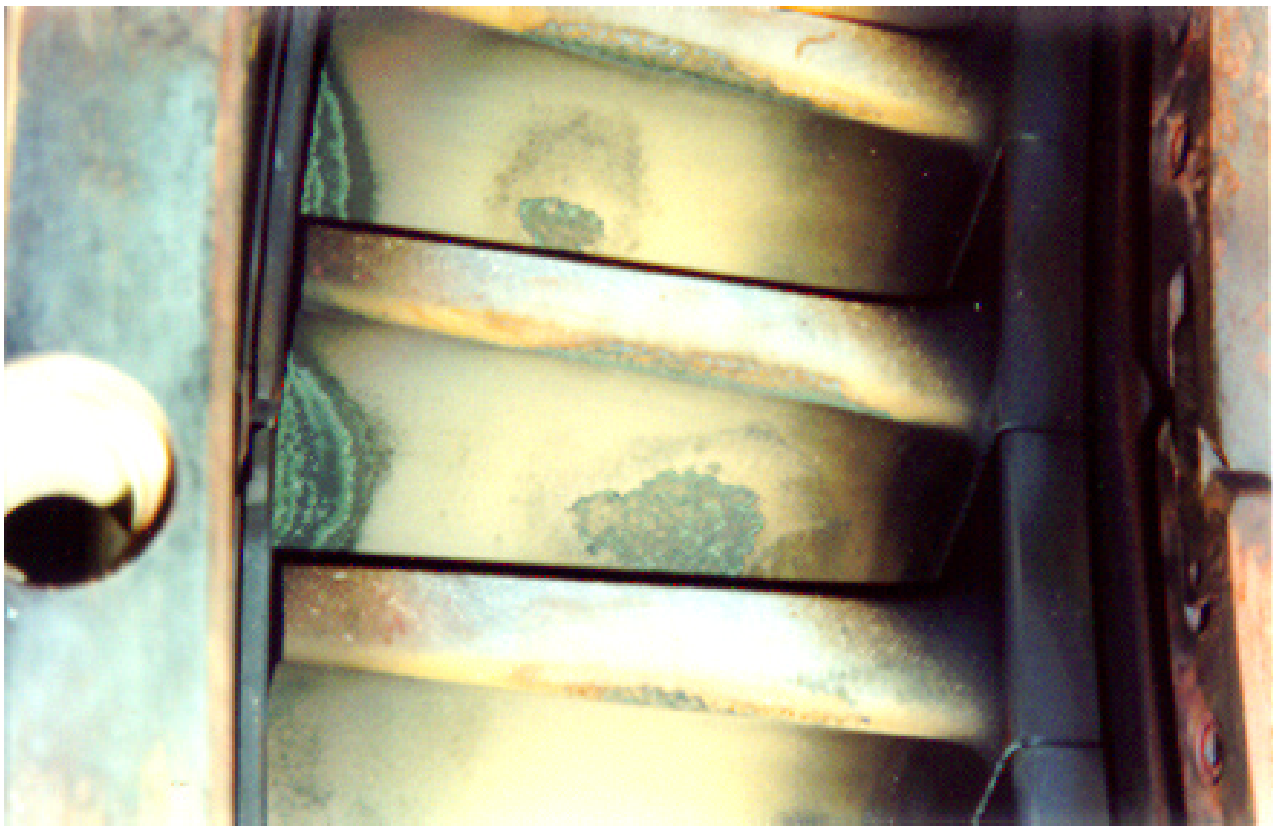
# DETAILS OF FIRST STAGE ROTATING BLADES



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# 1ST STAGE BLADE CRACKS CONCLUSIONS

- DURING 3 HGPI CRACKS ON 1ST STAGE PLATFORM AFTER COATING STRIPPING WERE FOUND
- THESE CRACKS WERE NOT DETECTED BY DYE PENETRANT TESTS CARRIED OUT ON COATED BLADES
- THE MOST SUSPECTED CAUSES ARE THE HIGH TEMPERATURE AND TENSO-CORROSION PHENOMENON DURING COATING STRIPPING
- IN ORDER TO DETECT THE FAILURE, ENEL CARRIES OUT PARTICULARLY EDDY CURRENT TESTS ON 1ST STAGE BLADE PLATFORMS EVERY 8000 EOH DURING CI WITHOUT BLADE REMOVAL

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# CONCLUSIONS

- ENEL FLEET CONSISTS OF 20 HEAVY DUTY GAS TURBINES CONNECTED WITH STEAM TURBINES IN COMBINED AND REPOWERED CYCLE
- IN ORDER TO INCREASE THE AVAILABILITY OF THESE STEAM-GAS COMBINED UNITS, IT IS IMPORTANT TO REDUCE THE MAINTENANCE ACTIVITIES OF GAS TURBINES
- IN ORDER TO PREVENT PARTICULAR FAILURES EXPERIENCED IN THE PAST, ENEL TUNED UP AND SCHEDULES SPECIAL DETECTING TECHNOLOGIES